J. Pestic. Sci. **49**(1), 15–21 (2024)
DOI: 10.1584/jpestics.D23-042

JOURNAL OF PESTICIDE SCIENCE

Regular Article

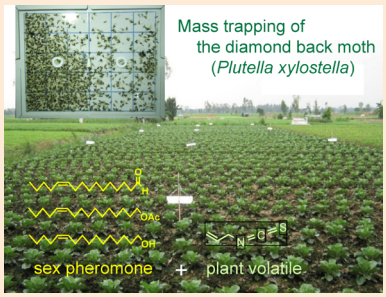
Mass trapping of the diamondback moth (*Plutella xylostella* L.) by a combination of its sex pheromone and allyl isothiocyanate in cabbage fields in southern Vietnam

Dinh Thi Chi,[1,2] Ho Le Thi,[1] Le Van Vang,[1,*] Tran Thanh Thy,[3] Masanobu Yamamoto[4] and Tetsu Ando[4]

[1] *College of Agriculture, Can Tho University, 3/2 street, Ninh Kieu District, Can Tho City, Vietnam*
[2] *Soc Trang Community College, Soc Trang Province, Vietnam*
[3] *Tan Tao University, Long An Province, Vietnam*
[4] *Graduate School of Bio-Applications and Systems Engineering, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184–8588, Japan*

(Received August 21, 2023; Accepted October 22, 2023)

A lure composed of (*Z*)-11-hexadecenal, (*Z*)-11-hexadecenyl acetate, and (*Z*)-11-hexadecen-1-ol at a ratio of 5:5:1 at a dose of 0.01 mg was optimal for the attraction of the Vietnamese strain of the diamondback moth (DBM). The combination of the sex pheromone with a plant volatile, allyl isothiocyanate, significantly increased the attraction of the pheromone trap. Females were also attracted, but they were only about 2% of all moths captured. In plots with 120–130 traps per ha, mass trapping with the combined lures reduced the DBM larval densities in cabbage fields as effectively as the spraying of insecticides 6 to 8 times. The weekly trap catches indicated that DBM adult densities in the mass-trapping fields were low until 28 days after transplantation, and then were kept to a modest increase until day 49. This field study also shows that the trap catches were well correlated with the DBM larval densities.



Keywords: pest control, pheromone application, IPM program, semiochemical, moth attraction, population dynamics.

Introduction

Cabbages (*Brassica oleracea* var. *capitata*) and other crops belonging to the *Brassica* genus in the Brassicaceae (=Cruciferae) family are cultivated worldwide and are considered of economic significance.[1,2] According to FAOStat (2023), the global area of cabbage harvested in 2021 was 2,450,601 ha, of which Vietnam accounted for 1.53% with 37,571 ha, ranking as the ninth largest area of cabbage harvest in the world.[3] In southern Vietnam, areas for growing cabbage and other *Brassica* crops are concentrated in Lam Dong Province and the Mekong Delta.

The diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae), is a specialist insect that is one of the most harmful pests of cruciferous vegetables in the world.[4,5] Spraying insecticides is the preferred method of controlling DBM in southern Vietnam. To obtain effective control, cruciferous vegetable growers had to spray insecticides at high doses and at short intervals.[9] Aside from the severe damage, DBM is able to resist 101 active ingredients of insecticides, even including insect growth regulators and *Bacillus thuringiensis*.[6] Its high resistance ability led to less effective control by conventional methods with the application of insecticides. Moreover, the damage status of DBM increased rapidly when chemical insecticides were applied to vegetable crops on a large scale.[7] Zalucki *et al.* estimated the cost of global control of DBM damage to cabbage, cauliflower, broccoli, and canola at 4.5 billion USD in a farming system with insecticide applications, while the estimated cost was just 2.6 billion USD in a farming system with threshold-based integrated pest management (IPM).[8] The implementation of IPM was considered the clear solution for managing DBM damage.[7,10] The application of semiochemicals such as pheromones and volatile organic compounds (VOCs) as tools for sustainable pest management has increased, with monitoring population dynamics and mass trapping by attraction lures considered an effective alternative to the use of broad-spectrum insecticides to con-

* To whom correspondence should be addressed.
E-mail: lvvang@ctu.edu.vn
Published online February 21, 2024

trol major insect pests.[11] Therefore, studies on the applications of sex pheromones incorporated with other semiochemicals as tools for IPM programs that reduce the use of insecticides in the control of DBM are necessary.

The sex pheromone of DBM was identified as a mixture of (*Z*)-11-hexadecenal (Z11-16:Ald) and (*Z*)-11-hexadecenyl acetate (Z11-16:OAc).[12] The 1:1 mixture attracted DBM males as strongly as did virgin females in the field.[13] Further field evaluation of synthetic analogs showed the synergistic effect of (*Z*)-11-hexadecen-1-ol (Z11-16:OH) on it.[14] The synthetic DBM pheromone has been utilized as a tool for monitoring population dynamics, mass trapping, and mating disruption.[15–17] The data of the pheromone trap attraction inform the optimum timing of insecticide spraying against DBM.[18] Moreover, Wang *et al.* reported that the combination of mass trapping by pheromone lures and killing with sprays of *Bacillus thuringiensis* and insecticides decreased the population densities of DBM in cabbage fields of Ha Noi, northern Vietnam.[19]

On the other hand, VOCs emitted from disrupted tissues of brassica and other plants, such as benzaldehyde, phenylacetaldehyde, allyl isothiocyanate (AITC), hexan-1-ol, (*Z*)-3-hexen-1-ol, and (*Z*)-3-hexenyl acetate (Z3-6:OAc), can attract DBM male and female adults; field studies in India and China demonstrated a potent attraction lure by combining DBM sex pheromone and Z3-6:OAc.[20,21] However, the synergistic effect of VOCs on the synthetic pheromone has not been examined in Vietnam. Therefore, we first optimized the mixing ratio and dose of the synthetic pheromone lure for the DBM strain in southern Vietnam. Next we found a plant volatile component that showed strong synergistic effects, and then we conducted mass trapping by utilizing the combination of the pheromone and plant volatiles.

In addition to the direct control using the pheromone, information regarding the correlation between the number of adults captured by traps and the larval density in a field is important because it might be effective as a reference to determine the action threshold for control of pest insects. However, their correlation has not been known, at least for DBM inhabiting cabbage fields in Vietnam. Our experiments made clear the population dynamics in the mass trapping fields; therefore, this paper also deals with the results of analyzing this correlation.

Materials and methods

1. Insects

Larvae of DBM were collected from cabbage fields in Binh Tan District (Vinh Long Province) and Cai Rang District (Can Tho City) and brought to Can Tho University. In the laboratory, the collected larvae were placed in transparent plastic boxes (12 cm×10 cm×7 cm) and supplied with a diet of fresh cabbage leaves. The boxes were placed in room conditions (photo regime of approximately 12L:12D; 27–30°C), cleaned, and supplemented with new cabbage leaves every day until insect pupation. Each pupa was transferred to a plastic cup (5.0 cm in diameter, 5.5 cm in height) containing a piece of moist cotton wool. After eclosion, male and female adults were distinguished by inspecting their abdominal tips,[22] and they were fed a 10% honey water solution, which was loaded on a small cotton wool ball in the cup.

2. Chemicals and leaf solutions

Three synthetic pheromone components (Z11-16:Ald, Z11-16:OAc, and Z11-16:OH with >96% purity) were supplied from our previous research.[23] AITC and Z3-6:OAc were purchased from Sigma-Aldrich Chemical Co., Inc. (U.S.A.). The leaf solution was prepared just before each field examination. A fresh cabbage leaf was crushed in a small porcelain mortar with a pestle and squeezed to extract the juice. The extract juice (about 1.0 mL) was loaded on a small cotton wool ball, which was placed at the center of a sticky board in a trap.

3. Examination of field attraction

The experiment was conducted at cabbage fields in Cho Moi District in An Giang Province. A rubber septum (0.2 cm in diameter, 0.5 cm in length), which was used as a connector in grafting of tomato seedlings,[24] was impregnated with synthetic pheromone components, AITC, or Z3-6:OAc to make a lure for trapping. In experimental fields, the lure was placed at the center of a sticky board of a delta trap (30×27 cm bottom plate, Takeda Chemical Ind., Ltd., Osaka, Japan) and hung on a bamboo stake at a height of 0.5 m from the ground. In experiments evaluating the effects of plant volatiles, two septa baited with the synthetic pheromone or a plant volatile were placed in the same trap. A trap baited with a blank rubber septum or one virgin female confined in an iron tea strainer (6 cm in diameter, 3 cm in height) was used as a negative or positive control, respectively. The confined female was fed by a small cotton wool ball wetted with a 10% honey water solution and replaced every week. Numbers of DBM adults captured by traps were counted weekly. In order to avoid a positional effect, the positions of traps in each experimental block were randomly changed after counting the captured males.

4. Mass trapping of DBM by attraction traps

The experiment was conducted twice in cabbage fields at Anh Dao Farm, Da Lat City, Lam Dong Province (Test 1) and My Xuyen District, Soc Trang Province (Test 2) with four trial plots for each test. Namely, (1) each mass-trapping plot was treated by hanging attraction traps at a density of 120–130 traps/ha; (2) each mixed plot was treated by hanging attraction traps (at the same density as that of the mass-trapping plots) and two sprays of insecticides; (3) each insecticide-treated plot was treated with 6 or 8 sprays of insecticides; and (4) control plots were cabbage fields without any treatment. The cabbage plants in the experimental plots were at 14 days after transplantation. Test 1 had been conducted for 8 weeks. Test 2 was finished at 7 weeks because, due to hot weather, the cabbage crops were harvested earlier than in the field of Test 1. Each trap was baited with two rubber septa, one of which was impregnated with 0.01 mg of the 5:5:1 ratio mixture of Z11-16:Ald, Z11-16:OAc, and Z11-

Table 1. Attraction of DBM (*Plutella xylostella*) by traps baited with single- or multi-component lures prepared from three pheromone compounds[a)]

Lure component (mg/septum)			Males/trap/week[b)]	
Z11-16:Ald	Z11-16:OAc	Z11-16:OH		
Test 1				
0.50	0.00	0.00	0.5±0.4	e
0.00	0.50	0.00	1.2±0.9	de
0.00	0.00	0.05	2.3±1.0	cde
0.25	0.25	0.00	55.7±25.4	b
0.50	0.00	0.05	3.42±1.8	cd
0.00	0.50	0.05	9.2±12.7	c
0.25	0.25	0.05	158.1±61.2	a
One virgin female[c)]			149.6±18.3	a
Blank (control)			0.0	
Test 2				
0.25	0.25	0.005	152.4±62.6	b
0.25	0.25	0.05	225.4±59.0	ab
0.25	0.25	0.10	246.7±100.3	ab
One virgin female[c)]			434.5±34.6	a
Blank (control)			0.0	

[a)] Experiments were carried out at a cabbage field in Cho Moi district, An Giang province from 28 December, 2013 to 25 January, 2014 (Test 1) and 3 February to 3 March, 2014 (Test 2). [b)] Mean±S.E. (n=3). Values within each test followed by the same letter are not significantly different at $p<0.05$ by Tukey–Kramer Test. [c)] Virgin female was replaced every week.

16:OH, and another was impregnated with 0.5 mg of AITC. The lures were renewed 4 weeks after the start. The numbers of captured DBM adults in traps and larvae feeding cabbage plants in trial plots were recorded weekly. The larval density of each trial plot was estimated by counting the larvae on 15 randomly selected cabbage plants growing at 5 different locations (4 on the peripheral and one in the central area). In order to avoid being disturbed by data-recording actions, cabbage plants in a slightly offset location were selected for the subsequent recording.

5. Data analysis

Data obtained in each field test were analyzed by one-way ANOVA, and pairwise comparisons among traps were performed with Tukey–Kramer Test with p-values adjusted for multiple comparisons. In order to homogenize the variance, means were transformed by using log (x+0.5) transformation. Treatments with zero catches were omitted from the ANOVA. All statistical analyses were performed with R version 3.0.1.[25)]

Results

1. Field attraction of DBM by synthetic sex pheromones

Table 1 shows the field attraction of DBM males to lures prepared from synthetic Z11-16:Ald, Z11-16:OAc, and Z11-16:OH components. Only lures made from all three components attracted DBM males as strongly as the attraction of a virgin female (Test 1). This affirmed the role of Z11-16:OH in the attraction of DBM males in the south of Vietnam. Further, the attraction between 5:5:1 and 5:5:2 mixing ratios was not significantly different, 10% was a suitable ratio of Z11-16:OH in the lure for the attraction of DBM males (Test 2). In the dose-effect examination, among tested doses from 0.01 to 1.0 mg, the 0.01–0.05 mg doses were optimal for attracting the DBM males in the field (Table 2).

2. Field attraction by a combination of sex pheromones and plant volatiles

Our preliminary field experiments showed that AITC, Z3-6:OAc, and cabbage leaf-ground solution attracted DMS adults. Selective attraction to males was observed, with approximately 90% of the attracted DBMs being males. Since the optimal doses of AITC and Z3-6:OAc were 0.5 and 0.05 mg/septum, respectively, the effects of these synthetic plant volatiles and leaf solution on the pheromone lure were examined (Table 3). Traps baited with a combination of the synthetic pheromone (5:5:1 mixture, 0.01 mg/septum) and AITC (0.5 mg/septum) captured significantly more DBM adults than those baited with the pheromone, AITC, Z3-6:OAc, or cabbage leaf-ground solution alone. The capture of DBM females by the combination lures was 1.7–5.5% of the total trap catches. Although the leaf solution also showed a synergistic effect on the pheromone, Z3-6:OAc did not affect the activity of the pheromone lure. Interestingly, the addition of Z3-6:OAc to lures reduced the synergistic effect of AITC.

3. Effect of mass strapping on DBM larval density

Table 4 shows the density of DBM larvae in trial plots treated with attraction traps and/or insecticides. These treated plots were not significantly different from those of the control until 4 weeks after the experiment's start, with the exception of the densities in the plot treated with both (mixed plot) in Test 1 and the insecticide-treated plot in Test 2, due to the initial low density of DBM larvae on fields during the early crop season. At

Table 2. Attraction of DBM (*Plutella xylostella*) by traps baited with lures containing different doses of a 5:5:1 mixture of Z11-16:Ald, Z11-16:OAc, and Z11-16:OH[a)]

Lure (mg/septum)	Males/trap/week[b)]	
0.01	202.6±113.0	a
0.05	225.3±71.0	a
0.1	142.5±98.4	ab
0.3	90.8±71.1	bc
0.5	109.8±53.3	bc
0.7	45.9±17.0	c
1.0	70.5±43.0	bc
One virgin female[c)]	310.3±24.2	a
Blank (control)	0.0	

[a)] Experiments were carried out at a cabbage field in Cho Moi district, An Giang province from 16 February to 16 March, 2014. [b)] Mean±S.E. (n=3). Values within each test followed by the same letter are not significantly different at $p<0.05$ by Tukey–Kramer Test. [c)] The female was replaced every week.

Table 3. Attraction of DBM (*Plutella xylostella*) by traps baited with the sex pheromone (mixture of Z11-16:Ald, Z11-16:OAc, and Z11-16:OH in a ratio of 5 : 5 : 1), allyl isothiocyanate (AITC), Z3-6:OAc and/or a grinded solution of cabbage leaves[a)]

Lure component (mg/septum)				Adults/trap/week[b)]							
Pheromone	AITC	Z3-6:OAc	Leaf solution[c)]	Male		Female (%)			Total		
0.01	0.0	0.00	−	91.3±25.9	bc	0.0±0.0			91.3±25.9	bc	
0.01	0.5	0.00	−	219.5±29.6	a	3.7±1.6	ab	(1.7)	223.2±28.7	a	
0.01	0.0	0.05	−	95.1±55.9	bc	3.0±1.8	ab	(3.1)	98.1±56.2	bc	
0.01	0.0	0.00	+	175.8±25.9	ab	5.2±4.3	ab	(2.9)	180.9±21.8	ab	
0.01	0.5	0.05	−	80.9±31.4	bc	2.2±1.0	b	(2.6)	83.1±32.1	bc	
0.01	0.5	0.05	+	99.6±33.4	bc	5.8±2.9	a	(5.5)	105.4±30.4	bc	
0.00	0.5	0.00	−	42.2±38.7	d	3.2±0.6	ab	(7.1)	45.2±38.2	d	
0.00	0.0	0.05	−	36.0±25.2	d	4.0±1.3	ab	(10.0)	40.2±24.3	d	
0.00	0.0	0.00	+	68.6±24.0	cd	5.0±1.5	ab	(6.8)	73.6±25.4	cd	
One virgin female[d)]				159.4±26.5	ab	0.0			159.4±26.5	ab	
Blank (control)				0.0		0.0			0.0		

[a)] Experiments were carried out at a cabbage field in Cho Moi district, An Giang province from 12 March to 9 April, 2015. [b)] Mean±S.E. (n=3). Values within each test followed by the same letter are not significantly different at $p<0.05$ by Tukey–Kramer Test. [c)] Leaf solution was renewed every 3 days. [d)] Virgin female was replaced every week.

8 weeks after the experiment's start, the densities of DBM larvae in the mass trapping, mixed and insecticide-treated plots in Test 1 were not significantly different from each other, while they were all significantly lower than in the control. These findings indicated that mass trapping at the rate of 120 traps per ha with combination lures of sex pheromones (0.1 mg) and AITC (0.5 mg) reduced the densities of DBM larvae as effectively as spraying insecticides 8 times. Although the density of DBM larvae in the mass trapping and mixed plots had a lower trend as compared with that of the control, they were not significantly different from each other. Furthermore, the increasing rates of DBM larval densities in mass trapping plots were 2.7 in Test 1 and 2.2 in Test 2, which were equal to or even lower than those in plots treated with insecticides (4.4 in Test 1 and 2.1 in Test 2). Meanwhile, the increasing rates of DBM larval densities in control plots were 8.1 in Test 1 and 4.1 in Test 2, which are 2 to 4 times higher than those in the mass-trapping plots. These revealed that the efficiency of mass trapping by sex pheromones in combination with AITC increased over time of application.

4. *Correlation of larval and adult density in the mass-trapping fields*

Figure 1 shows the weekly trap catches of DBM adults in the mass-trapping and mixed-trial plots. Although the numbers of DBM adults captured by attraction traps were different between the two experimental sites (Test 1 in Lam Dong Province and

Table 4. Control of larval density of DBM (*Plutella xylostella*) at cabbage fields by treatment with attractant traps and/or insecticides[a)]

Trial plot		Number of DBM larvae (larvae/plant)[b)]						
Treatment	Area (m^2)	Duration after the start of the treatment						Increasing rate
Test 1		2 weeks (A)		4 weeks		8 weeks (B)		(B/A)
Six traps (120 traps/ha)	500	2.5±0.6	a	0.8±0.3	ab	6.7±3.0	b	2.7
30 traps+two sprays of insecticides	2500	1.3±0.4	c	0.4±0.3	b	5.0±2.1	b	3.8
Six sprays of insecticides[c)]	700	1.6±0.3	bc	0.9±0.3	ab	7.0±2.8	b	4.4
Control	300	1.7±0.5	ab	1.1±0.5	a	13.7±3.6	a	8.1
Test 2		2 weeks (A)		4 weeks		7 weeks (B)		
Nine traps (*ca.* 130 traps/ha)	700	2.6±0.8		2.2±0.8	a	5.6±1.9	ab	2.2
Nine traps+two sprays of insecticides	700	3.2±1.4		1.5±0.6	ab	7.9±2.8	ab	2.5
Eight sprays of insecticides[d)]	760	1.7±0.7		0.9±0.6	b	3.6±0.9	b	2.1
Control	140	2.3±1.4		2.7±0.8	a	9.4±2.5	a	4.1

[a)] Test 1 was carried out at Anh Dao Farm, Da Lat city, Lam Dong province from 25 February to 22 April, 2017. Test 2 was carried out at Tham Don ward, My Xuyen district, Soc Trang province from 1 January to 17 February, 2018. Cabbage seedlings were planted 2 weeks before the start of each test, and the cabbages were harvested 10 and 9 weeks after the planting in Lam Dong and Soc Trang, respectively. [b)] Mean±S.E. (n=5). Values within each test followed by the same letter are not significantly different at $p<0.05$ by Tukey–Kramer Test. [c)] Sprays of diazinon, cypermethrin, emamectin benzoate, or *Bacillus thuringiensis* during the cultivation period (about 10 weeks). [d)] Sprays of profenofos or emamectin benzoate during the cultivation period (about 9 weeks).

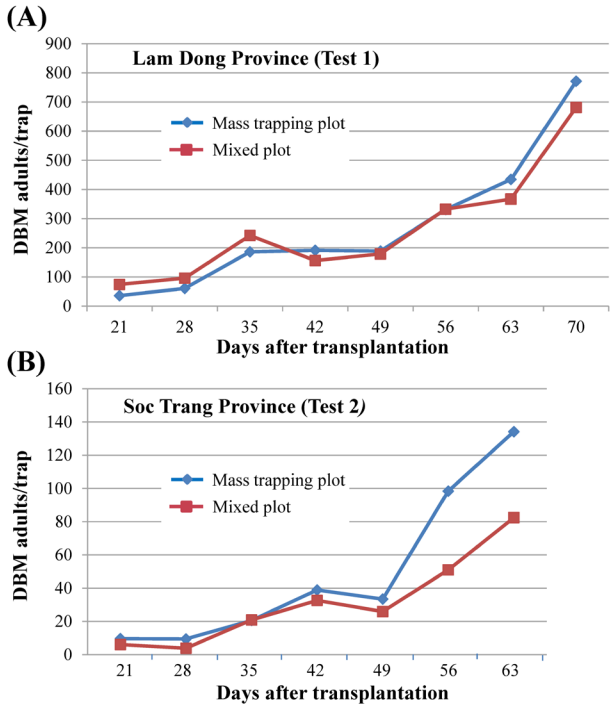


Fig. 1. Weekly trap catches of DBM adults by attraction traps in mass-trapping fields in Lam Dong Province of Test 1 (A) and Soc Trang Province of Test 2 (B).

Test 2 in Soc Trang Province), their weekly fluctuations were similar. The trap catches were low at the beginning of the crop season, started to increase 28 days after transplantation (two weeks after the experiment's start), remained low until 49 days after transplantation, and then rapidly increased until harvest. Interestingly, the numbers of DBM adults captured by the attraction traps positively correlated with the DBM larval densities, with the correlation coefficients (r) in Test 1 and Test 2 being 0.98 and 0.74, respectively (Fig. 2). This information would be useful for estimating the pest's damage threshold.

Discussion

The optimum mixing ratio of three components (Z11-16:Ald, Z11-16:OAc and Z11-16:OH) for attracting DBM males was examined in several countries, and different values were reported as follows: 10:10:1 in Japan, 50:50:1 in Taiwan, 10:90:1 in Korea, and 6:3:1 in New Zealand.[26] In the Vietnamese strain, Wang *et al.* reported that the 50:50:1 mixture (0.05 mg/septum) effectively attracted DBM males in the northern area.[19] However, our experiments conducted in southern Vietnam show that the 5:5:1 ratio is the best (Table 1) at the same dose on the septum (Table 2). Since Vietnam is a relatively long country from north to south, further investigation is required to know how the responses of male moths differ from region to region.

In order to develop a strong attraction lure for mass trapping, we examined the effects of AITC and Z3-6:OAc. AITC is a breakdown product of its glucosinolates produced by cruciferous plants. AITC is toxic to generalist insects but acts as a feeding and oviposition stimulant to Brassica-specialist insects.[27–29] However, Z3-6:OAc, which is a common plant green leaf volatile,[30] acts as a pheromone enhancer on several moth species, such as the oriental fruit moth.[31] In the case of DBM, Dai *et al.* reported the results of field tests in China on the attractant activities of AITC, Z3-6:OAc, and other plant volatiles.[21] These compounds were less active than the synthetic pheromones, but they also attracted female moths. The females accounted for 5–15% of the total, which is consistent with our result (Table 3). This is an important result because the capture of females, even if limited in number, could directly influence the population density of the next generation. Their field tests also demonstrated the synergistic effect of Z3-6:OAc on the attraction of the synthetic pheromone but no effect of AITC. However, our experiments in Vietnam remarkably showed the opposite result, AITC being a synergist and Z3-6:OAc not (Table 3). Interestingly, Z3-6:OAc worked to counteract the synergistic effect of AITC. It is not clear why our results differed from those in China, but we decided to carry out mass-trapping experiments, applying a combina-

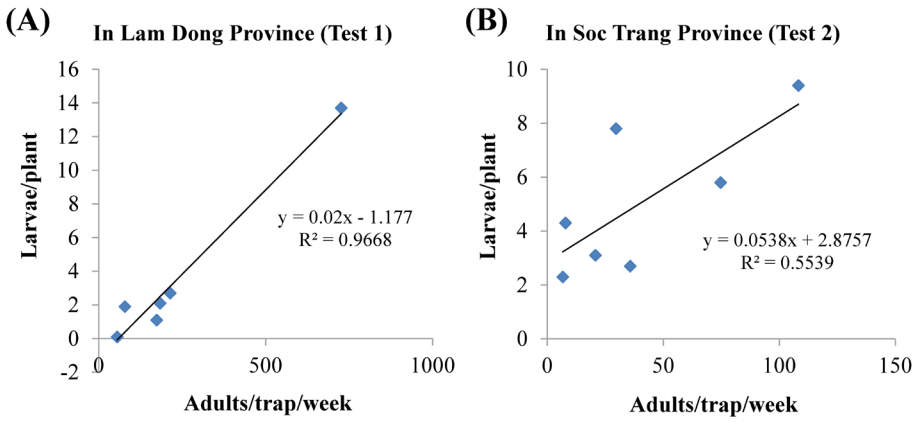


Fig. 2. Correlations between the weekly trap catches of DBM adults and densities in mass-trapping fields in Lam Dong Province of Test 1 (A) and Soc Trang Province of Test 2 (B).

tion of two lures baited with the pheromone (0.01 mg) or AITC (0.5 mg).

The mass trapping of DBM by a combination lure of sex pheromones and AITC at a rate of 120–130 traps/ha reduced the densities of DBM larvae as effectively as spraying insecticides 6 to 8 times. Moreover, the slowly increasing rates of DBM larval densities in the mass-trapping plot revealed that the longer mass trapping was applied, the more effective was the reduction of DBM larval densities in the field (Table 4). Additionally, the fluctuation of the weekly trap catches and the positively tight correlation of the weekly trap catches and larval densities (Figs. 1 and 2) would be useful information for estimating the pest's damage threshold. Studies on the mass trapping of DBM by sex pheromone traps have been reported.[15,19,32] While the previous experiments utilized lures including only pheromone components, our study revealed the efficiency of mass trapping of DBM by a combination with sex pheromones and AITC. Although the mass trapping experiment did not include a test plot using the AITC-free pheromone lure, and it is not possible to show specifically how much AITC contributes to the reduction of larval density, AITC is expected to make a significant contribution, considering its strong synergistic activity for the pheromone lure and incontrovertible attraction activity for females.

Lure optimization field tests were carried out in Cho Moi District (10°33′N 105°24′E) in An Giang Province. Mass trapping was done in Da Lat City (11°56′30″N 108°26′18″E) in Lam Dong Province and My Xuyen District (9.417°N 105.783°E) in Soc Trang Province. An Giang Province and Soc Trang Province are located in the Mekong Delta, which has a typically subtropical monsoon climate with hot and wet weather. Their monthly temperatures are above 26°C. Da Lat City, located in the west highlands at an altitude of over 1500 m, has a typical mountain zone climate with a monthly temperature of less than 20°C. Mass trapping in the highlands using the lures selected by the field test in the hot Mekong Delta (Table 4, Test 1) showed good pest control efficacy as the mass trapping in the Mekong Delta (Test 2). These results indicate that adults in these two regions with very different climates responded similarly.

The technique for mating disruption has been established for the DBM control. However, dispensers including its synthetic pheromone are not commercially available in Vietnam because they are more expensive than the usual pesticides. On the other hand, mass trapping requires only small amounts of synthetic pheromones; therefore, it is a promising pest control method. Mass-trapping attempts are still limited, and there is a need for the further accumulation of field data. The development of inexpensive and easy-to-handle traps is also necessary. This study is a first important step of the IPM programs toward controlling DBM and some other lepidopteran pest species in southern Vietnam.

References

1) M. E. Cartea, M. Francisco, P. Soengas and P. Velasco: Phenolic compounds in *Brassica* vegetables. *Molecule* **16**, 251–280 (2011).
2) B. Salehi, C. Quispe, M. Butnariu, I. Sarac, I. Marmouzi, M. Kamle, V. Tripathi, P. Kumar, A. Bouyahya, E. Capanoglu, F. D. Ceylan, L. Singh, I. D. Bhatt, B. Sawicka, B. Krochmal-Marczak, D. Skiba, M. El-Jemli, Y. El-Jemli, E. Coy-Barrera, J. Sharifi-Rad, S. Kamiloglu, M. de la Luz Cádiz-Gurrea, A. Segura-Carretero, M. Kumar and M. Martorell: Phytotherapy and food applications from *Brassica* genus. *Phytother. Res.* **35**, 3590–3609 (2021).
3) FAOSTAT Food and Agriculture Data: Production, Crops and livestock products. https://www.fao.org/faostat/en/#data/QCL (Accessed 18 Aug. 2023)
4) D. F. Waterhouse: The major arthropod pests and weeds of agriculture in Southeast Asia: distribution, importance and origin. ACIAR (Australian Centre for International Agricultural Research) monograph series, 141 pp., 1993.
5) N. S. Talekar and A. M. Shelton: Biology, ecology, and management of the diamondback moth. *Annu. Rev. Entomol.* **38**, 275–301 (1993).
6) Arthropod pesticide resistance database. https://www.pesticideresistance.org/index.php (Accessed 18 Aug. 2023)
7) S. Liu, X. Wang, S. Guo, J. He and Z. Shi: Seasonal abundance of the parasitoid complex associated with the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) in Hangzhou, China. *Bull. Entomol. Res.* **90**, 221–231 (2000).
8) M. Zalucki, A. Shabbir, R. Silva, D. Adamson, L. Shu-Sheng and M. Furlong: Estimating the economic cost of one of the world's major insect pests, *Plutella xylostella* (Lepidoptera: Plutellidae): Just how long is a piece of string? *J. Econ. Entomol.* **105**, 1115–1129 (2012).
9) N. V. Huynh and L. T. Sen: "Crop Damaging Insects," Agricultural Press, 288 pp., 2017 (in Vietnamese).
10) M. J. Furlong, D. J. Wright and L. M. Dosdall: Diamondback moth ecology and management: Problems, progress, and prospects. *Annu. Rev. Entomol.* **58**, 517–541 (2013).
11) A. M. El-Sayed, D. M. Suckling, C. H. Wearing and J. A. Byers: Potential of mass trapping for long-term pest management and eradication of invasive species. *J. Econ. Entomol.* **99**, 1550–1564 (2006).
12) Y. Tamaki, K. Kawasaki, H. Yamada, T. Koshihara, N. Osaki, T. Ando, S. Yoshida and H. Kakinohana: (*Z*)-11-Hexadecenal and (*Z*)-11-hexadecenyl acetates: Sex-pheromone components of the diamondback moth (Lepidoptera: Plutellidae). *Appl. Entomol. Zool.* **12**, 208–210 (1977).
13) T. Koshihara, H. Yamada, Y. Tamaki and T. Ando: Field attractiveness of the synthetic sex pheromone of the diamondback moth, *Plutella xylostella* (L.). *Appl. Entomol. Zool.* **13**, 138–141 (1978).
14) T. Ando, T. Koshihara, H. Yamada, M. H. Vu, N. Takahashi and Y. Tamaki: Electroantennogram activities of sex pheromone analogues and their synergistic effect on field attraction in the diamondback moth. *Appl. Entomol. Zool.* **14**, 362–364 (1979).
15) G. V. P. Reddy and K. C. D. Urs: Mass trapping of diamondback moth *Plutella xylostella* in cabbage fields using synthetic sex pheromones. *Int. Pest. Control* **39**, 125–126 (1997).
16) G. V. P. Reddy and A. Guerrero: Pheromone based integrated pest management to control the diamondback moth *Plutella xylostella* in cabbage fields. *Pest Manag. Sci.* **56**, 882–888 (2000).
17) P. C. Schroeder, A. M. Shelton, C. S. Ferguson, M. P. Hoffmann and C. H. Petzoldt: Application of synthetic sex pheromone for management of diamondback moth, *Plutella xylostella*, in cabbage. *Entomol. Exp. Appl.* **94**, 243–248 (2000).
18) G. V. P. Reddy and A. Guerrero: Optimum timing of insecticide applications against diamondback moth *Plutella xylostella* in cole crops using threshold catches in sex pheromone traps. *Pest Manag. Sci.* **57**, 90–94 (2001).

19) X.-P. Wang, V.-T. Le, Y.-L. Fang and Z.-N. Zhang: Trap effect on the capture of *Plutella xylostella* (Lepidoptera: Plutellidae) with sex pheromone lures in cabbage fields in Vietnam. *Appl. Entomol. Zool.* **39**, 303–309 (2004).
20) G. V. P. Reddy and A. Guerrero: Behavioral responses of the diamondback moth to green leaf volatiles of *Brassica oleracea* subsp. *capitata*. *J. Agric. Food Chem.* **48**, 6025–6029 (2000).
21) J. Dai, J. Deng and J. Du: Development of bisexual attractants for diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) based on sex pheromone and host volatiles. *Appl. Entomol. Zool.* **43**, 631–638 (2008).
22) Y.-X. Chen, H.-J. Tian, H. Wei, Z.-X. Zhan and Y.-Q. Huang: A simple method for identifying sex of *Plutella xylostella* (Linnaeus) larva, pupa and adult. *Fujian J. Agric.Sci.* **26**, 611–614 (2011).
23) D. T. Chi and L. V. Vang: Synthesis and field examinations of the sex pheromone of the diamondback moth, *Plutella xylostella* Linnaeus (Lepidoptera: Plutellidae) in the Mekong Delta of Vietnam. *Can Tho Univ. J. Sci* **54**, 1–6 (2018).
24) N. D. Thinh, L. K. An, C. N. Q. Khanh and L. V. Vang: Studying the optimal condition for trap application of sex pheromone of the citrus pock caterpillar, *Prays endocarpa* Meyrick (Lepidoptera: Yponomeutidae). *Can Tho Univ. J. Sci* **28**, 130–136 (2013) (in Vietnamese).
25) R Development Core Team: R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. https://cran-archive.r-project.org/bin/windows/base/old/3.0.1/ (2022)
26) Pheromone database. https://lepipheromone.sakura.ne.jp/lepi_phero_list.html (Accessed 18 Aug. 2023)
27) M. Sarfraz, L. M. Dosdall and B. A. Keddie: Diamondback moth-host plant interactions: Implications for pest management. *Crop Prot.* **25**, 625–639 (2006).
28) J. A. A. Renwick, M. Haribal, S. Gouinguené and E. Städler: Isothiocyanates stimulating oviposition by the diamondback moth, *Plutella xylostella*. *J. Chem. Ecol.* **32**, 755–766 (2006).
29) A. H. K. Robin, M. R. Hossain, J.-I. Park, H. R. Kim and I.-S. Nou: Glucosinolate profiles in cabbage genotypes influence the preferential feeding of diamondback moth (*Plutella xylostella*). *Front. Plant Sci.* **8**, 01244 (2017).
30) M. Ameye, S. Allmann, J. Verwaeren, G. Smagghe, G. Haesaert, R. C. Schuurink and K. Audenaert: Green leaf volatile production by plants: a meta-analysis. *New Phytol.* **220**, 666–683 (2018).
31) H. Yu, J. Feng, Q. Zhang and H. Xu: (*Z*)-3-Hexenyl acetate and 1-undecanol increase male attraction to sex pheromone trap in *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae). *Int. J. Pest Manage.* **61**, 30–35 (2015).
32) S. Imran, G. P. Mutthuraju, B. Doddabasappa, G. K. Sudarshan, A. Sahida and A. K. Chakravarthy: Standardization of height and density of pheromone traps for mass trapping diamond back moth, *Plutella xylostella* (L.) in cabbage. *J. Entomol. Zool. Stud.* **7**, 1049–1052 (2019).